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(71) Applicant: SURFACE/INTERFACE, INC. [US/US]; 260 Santa Ana Court, Sunnyvale, CA 94086 (US).

(72) Inventors: MITCHELL, Thomas, Owen; 907 Sixth Avenue, Redwood City, CA 94603 (US). BRYSON, Charles, E., III; 2369 Benton Street, Santa Clara, CA 95050 (US). BERGHAUS, Andreas; 361 Haight Street, San Francisco, CA 94102 (US). SARKISSIAN, Vahe; 2200 Rolling Hills Road, Saratoga, CA 95070 (US).

(74) Agent: GUENZER, Charles, S.; Law Offices of Charles Guenzer, 2211 Park Boulevard, P.O. Box 60729, Palo Alto, CA 94306 (US).

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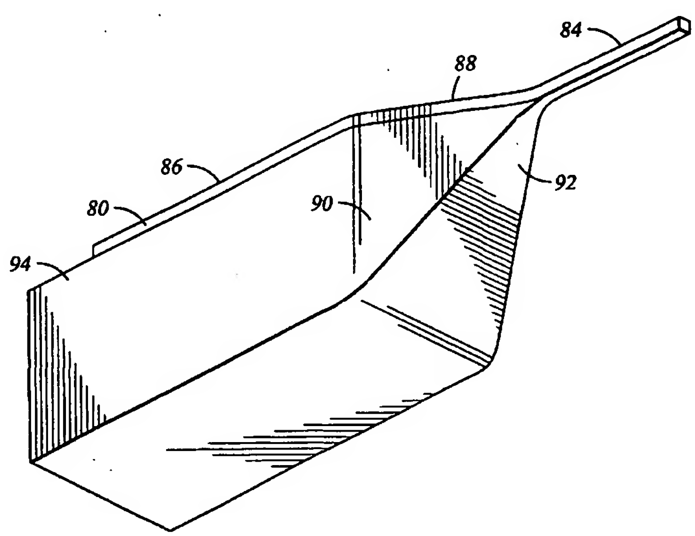
(54) Title: MICROMACHINED MICROPROBE TIP



(57) Abstract: A probe having a probe tip (84), especially for use in an atomic force microscope, formed by micromachining techniques in a silicon wafer (94). The tip is photolithographically defined in a layer (80), preferably of silicon nitride deposited on the silicon wafer and has a width and thickness of usually less than 250nm. Thereby, the probe tip can be formed to have a generally square cross section in which one lateral dimension is determined by the layer thickness, and the other lateral dimension by the photolithography or by a subsequent step of focused ion beam milling. The portion of the silicon wafer underlying the area probe tip is etched away, preferably before the probe tip is etched, but another portion of the silicon is left to serve as a support at the base of the probe tip. A hinge may be formed in the silicon wafer, and the probe tip together with a robust shank can be made to rotate to a direction perpendicular to the wafer surface.

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MICROMACHINED MICROPROBE TIP

FIELD OF THE INVENTION

The invention relates generally to scanning profilometers. In particular, the invention relates to probes for such profilometers fabricated by micromachining techniques.

BACKGROUND OF THE INVENTION

In semiconductor fabrication and related technologies, it has become necessary to routinely determine critical dimensions (CD), in either the vertical or horizontal direction, of physical features formed in substrates. An example, shown in the illustrative cross sectional view of FIG. 1, includes a trench 10 formed in a substrate 12, the depth of the trench 10 being greatly exaggerated with respect to the thickness of a silicon wafer 12. In advanced silicon technology, an exemplary width of the trench is 0.18μm, and its depth is 0.7μm. The critical dimension of the trench 10 may be the width of the top of the trench opening or may be the width of the bottom of trench 10. In other situations, the depth of the trench 10 is an important dimension. For the dimensions described above, the trench 10 has a high aspect ratio of greater than 4. Although in typical designs, sidewalls 14 of the trench 10 have ideal vertical profile angles of 90°, in fact the profile angle may be substantially less. Much effort has been expended in keeping the profile angle at greater than 85° or even 88° to 90°, but it requires constant monitoring of the system performance to guarantee that so sharp a trench is etched. As a result, it has become necessary, either in the development laboratory or on the production line, to measure the profile of the trench 10 with horizontal resolutions of 0.18μm and less. Depending upon the situation, the entire profile needs to be determined, particularly the sidewall angle, or the top or bottom trench width needs to be measured. More circular apertures, such as needed for inter-level vias, also need similar measurements. Similar requirements extend to measuring the profiles of vertically convex features such as interconnects.

To satisfy these requirements, profilometers based upon atomic force microscopy

(AFM) and similar technology has been developed which rely upon the vertical position of a probe tip 20, illustrated in FIG. 1. Lee et al. describe in UK Patent Application 2,009,409-A, published June 13, 1979, a jumping mode of operation involving a raster scan in which the probe tip 20 is continuously scanned in a horizontal direction while the probe tip 20 is being gradually lowered until it strikes the surface and is thereafter raised to a fixed height before being lowered again. Thereby, multiple height determinations are made along a scan line. Then, another line is scanned to enable imaging of the topography in two dimensions. Alternatively, in a pixel scan, the probe tip 20 is horizontally positioned over the feature to be probed, and then the probe tip 20 is gently lowered until it is stopped by an edge of the feature, preferably the top surface, and circuitry to be briefly described later then measures the height at which the probe tip stops. The probe tip 20 is then withdrawn to a height above any intervening features before the tip 20 is moved to the next position to be probed.

An example of such a critical dimension measurement tool is the Model 3010 available from Surface/Interface, Inc. of Sunnyvale, California. It employs technology similar to the rocking balanced beam probe disclosed by Griffith et al. in U.S. Patent 5,307,693 and by Bryson et al. in U.S. Patent 5,756,887. It is intended to be used in the pixel mode in which the probe is discontinuously scanned along a line. At a large number of discrete points, the lateral motion is stopped, and the probe is lowered until it encounters the surface being profiled. The tool is schematically illustrated in the side view of FIG. 2. A wafer 30 or other sample to be is supported on a support surface 32 supported successively on a tilt stage 34, an x-slide 36, and a y-slide 38, all of which are movable along their respective axes so as to provide horizontal two-dimensional and tilt control of the wafer 30. Although these mechanical stages provide a relatively great range of motion, their resolutions are relatively coarse compared to the resolution sought in the probing. The bottom y-slide 38 rests on a heavy granite slab 40 providing vibrational stability. A gantry 42 is supported on the granite slab 40. A probe head 44 hangs in the vertical z-direction from the gantry 42 through an intermediate piezoelectric actuator providing about 10μm of motion in (x, y, z) by voltages applied across electrodes attached to the walls of a piezoelectric tube. A probe 46 with tiny attached probe tip 20 projects downwardly from the probe head 44 to selectively engage the probe tip 20 with the top surface of the wafer 30

and to thereby determine its vertical and horizontal dimensions.

Principal parts of the probe head 44 of FIG. 2 are illustrated in orthogonally arranged side views in FIGS. 3 and 4. A dielectric support 50 fixed to the bottom of the piezoelectric actuator 45 includes on its top side, with respect to the view of FIG. 2, a magnet 52. On the bottom of the dielectric support 50 are deposited two isolated capacitor plates 54, 56 and two interconnected contact pads 58.

A beam 60 is medially fixed on its two lateral sides and is also electrically connected to two metallic and ferromagnetic ball bearings 62, 64. The beam 60 is preferably composed of heavily doped silicon so as to be electrically conductive, and a thin silver layer is deposited on it to make good electrical contacts to the ball bearings. However, the structure may be more complex as long as the upper surface of the beam 60 is electrically conductive in the areas of the ball bearings 62, 64 and of the capacitor plates 54, 56. The ball bearings 62, 64 are placed on the contact pads 58 and generally between the capacitor plates 54, 56, and the magnet 52 holds the ferromagnetic bearings 62, 64 and the attached beam 50 to the dielectric support 50. The attached beam 60 is held in a position generally parallel to the dielectric support 50 with a balanced vertical gap of about 25μm between the capacitor plates 54, 56 and the beam 60. Unbalancing of the vertical gap allows a rocking motion of about 25μm. The beam 60 holds on its distal end a glass tab 70 to which is fixed a stylus 72 having the probe tip 20 projecting downwardly to selectively engage the top of the wafer 12 being probed. An unillustrated dummy stylus or substitute weight on the other end of the beam 60 may provide rough mechanical balancing of the beam in the neutral position.

Two capacitors are formed between the respective capacitor plates 54, 56 and the conductive beam 60. The capacitor plates 54, 56 and the contact pads 58, commonly electrically connected to the conductive beam 60, are separately connected by three unillustrated electrical lines to three terminals of external measurement and control circuitry This servo system both measures the two capacitances and applies differential voltage to the two capacitor plates 54, 56 to keep them in the balanced position. When the piezoelectric actuator 45 lowers the stylus 72 to the point that it encounters the feature being probed, the beam 60 rocks upon contact of the stylus 72 with the wafer 30. The difference in capacitance between the plates 54, 56 is detected, and the servo circuit attempts to rebalance

the beam 60 by applying different voltages across the two capacitors, which amounts to a net force that the stylus 72 is applying to the wafer 30. When the force exceeds a threshold, the vertical position of the piezoelectric actuator 45 is used as an indication of the depth or height of the feature.

Conventionally, the probe 20 of FIG. 1 has a conically shaped probe tip 74 with sloped walls 76 generally forming a doubled apex angle 2α substantially greater than 0°. That is, the probe tip 20 has an acutely shaped tip 74 but with finitely sloped sidewalls 76.

A difficulty arises if the apex angle of α of the probe tip 74 is too large to allow the probe to test the sidewall angle of the trench 10 or, as illustrated in FIG. 1, to even reach the bottom corners 78 of the trench 10. In very general terms, if the angle α is greater than the sidewall slope, then the probe 20 is incapable of measuring the sidewall 14 and cannot accurately measure the width of the trench bottom. Of course, in the case that the sidewall profile varies from its top to bottom, whatever part has an angle less than that of the probe tip 20 cannot be measured. Efforts have been made to make cylindrical microprobes from optical fibers, see for example U.S. Patents 5,676,852 and 5,703,979 to Filas et al. However, this technique does not reliably produce the smaller diameters required for probing a 180nm trench.

A further problem with the conventional probe tip manufactured from silica optical fiber is that the very narrow portions are subject to significant deflection when they are subjected to a lateral force, for example, when the lowering probe tip encounters the sloping trench sidewall. The deflection reduces the vertical measurement accuracy and also renders suspect the horizontal position of the blocking feature, as measured by both the vertical and horizontal positions of the piezoelectric actuator 45.

SUMMARY OF THE INVENTION

The invention may be summarized as a probe tip and a preferred method of manufactured.

The probe tip has a generally rectangular cross section, preferably with a thickness of no more than 250nm. The probe tip is integral with a substrate, such as a silicon wafer, and the width of the tip is substantially less than that of the substrate. A tapered section connects the tip to the substrate.

The probe is preferably manufactured by micromachining techniques derived from the fabrication of silicon integrated circuits. For example, a layer of a non-silicon material is deposited over a silicon wafer to the thickness of the desired probe width. Silicon nitride is the most preferred material of the deposited layer, but other materials including silica, titanium nitride, sapphire, silicon carbide, and diamond may also be used.. Photolithographic techniques are used to form in the deposited layer both a probe tip having a width generally corresponding to desired probe width as well as a larger support structure at the proximal end of the probe tip. The portion of the backside of the silicon wafer underlying the probe tip is etched away to provide a cantilevered probe tip, which may be attached to the wafer in the support area. The wafer is diced around the support area to leave a free-standing probe tip and integral support. By this method, many probes may be simultaneously formed on the wafer.

The probe tip may be attached to the wafer through a hinge. After the formation of the probe tip, it is rotated about the hinge to project above the plane of the wafer. Part of the wafer serves as a support structure that is easily handled.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic cross-sectional view of a instrument for measuring critical dimensions in a silicon wafer.

FIG. 2 is a side view of a commercially available system for measuring critical dimensions.

FIGS. 3 and 4 are orthogonal side views of the probe head of the system of FIG. 2.

FIG. 5 is a cross-sectional view of a silicon wafer with the probe layer deposited but not laterally defined.

FIG. 6 is a cross-sectional view of the wafer of FIG. 5 with the probe layer etched into its final form.

FIG. 7 is a plan view of the wafer of FIG. 6.

FIG. 8 is a side cross-sectional view of the wafer of FIGS. 5 and 6 after the backside of the wafer has been selectively etched away.

FIG. 9 is an end elevational view of the probe after its separation from the growth wafer.

FIG. 10 is an orthographic view of the probe of FIG. 9.

FIG. 11 is a cross-sectional view of a wafer being probed by the probe tip of the invention.

FIG. 12 is a plan view of a wafer being fabricated with a large number of probes.

FIGS. 13 and 14 are respectively side elevational and plan views of a hinged probe assembly utilizing a hinge, the views being taken at the termination of micromachining and dicing.

FIGS. 15 and 16 are respectively side elevational and plan views of the probe of FIGS. 13 and 14 after the probe tip has been rotated into its operational position.

FIG. 17 is an elevational side view of the probe after the hinged probe has been immobilized in its operational position.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In recent years micromachining has been developed to fabricate micro electro-mechanical systems (MEMS) using techniques well developed in the fabrication of silicon integrated circuits. Review articles include Kovacs et al., "Bulk Micromachining of Silicon," *Proceedings of the IEEE*, vol. 6, 86, no. 8, August, 1998, pp. 1536-1551. Micromachining can be advantageously applied to fabricate a mechanical probe tip integrated with a support, as has been disclosed by Albrecht et al. in "Microfabrication of cantilever styli for the atomic force microscope," *Journal of Vacuum Science and Technology A*, vol. 8, no. 4, 1990, pp. 3386-3395, by Boisen et al. in "AFM probes with directly fabricated tips," *Journal of Micromechanics and Microengineering*, vol. 6, 1996, pp. 58-62, and by Tortonese in "Cantilevers and Tips for Atomic Force Microscopy," *IEEE Engineering in Medicine and Biology*, March/April 1997, pp. 28-33. Most of these microprobes have involved V-shaped cantilevered layers or pyramids projecting from a cantilevered layer. Albrecht et al. briefly discuss rectangular cantilevers but ones having a minimum width of 5μm, a minimum thickness of 0.4μm, and a minimum length of 100μm. These dimensions should be compared to a typical wafer thickness of 500μm. Albrecht et al. then suggest using a corner of a cantilever as a tip. Thus, their dimensions are incompatible with probing trenches and vias in integrated circuits

In one embodiment of the invention, as illustrated in the cross-sectional view of

FIG. 5, a probe layer 80 is deposited over a crystalline silicon wafer 82. For some types of micromachining the surface orientation of the silicon and the orientation of the probe relative to silicon crystalline axes are important. The wafer may be of standard thickness, but may be somewhat thinner, for example, 200μm. Other materials than silicon may be used for the substrate, and a thick layer of another may be deposited on a substrate and then etched away to leave a relatively thick support layer. However, a silicon wafer support is preferred.

The thickness of the probe layer 80 equals the desired width of the probe, for example, 160nm. The material of the probe layer 80 must be strong and be differentially etchable with respect to silicon. Examples of the material are silica (SiO_2), silicon nitride (Si_3N_4), and titanium nitride (TiN). All these materials are commonly grown to the thicknesses desired of the probe tip. Silica can be thermally oxidized from silicon or preferably is deposited by plasma-enhanced chemical vapor deposition (PECVD) using tetraethyorthosilicate (TEOS) as a precursor gas. Silicon nitride can be grown by PECVD using silane (SiH_4) and nitrogen (N_2) as precursors. Titanium nitride if usually formed by reactive sputtering of a titanium target in a nitrogen plasma, although CVD techniques are available. Some of these materials can be deposited in thin layers by other methods such as sol-gel.

Yet other materials may be chosen for the probe layer, including sapphire, silicon carbide, and diamond. However, we believe that silicon nitride is the preferred easily available material. It is known that the deflection for a circular probe tip of radius R and length L fixed and one end and subjected to a lateral force F at its other end is given by the equation

$$x = \frac{4FL^3}{3\pi YR^4}$$

where Y is Young's modulus. The relationship for a square probe would be nearly the same. TABLE 1 gives approximate values of Young's modulus for a number of common materials amenable to MEMS fabrication.

	Young's Modulus (GPa)
Fused Silica	73.2
Silicon	170
Polysilicon	169
Silicon Nitride	270
Sapphire	345
Silicon Carbide	466
Diamond	1000

TABLE 1

Of these materials, silicon nitride is the material having the highest Young's modulus and which can be easily integrated into conventional silicon processing. Silicon nitride affords a nearly four-fold increase in Young's modulus over the silica used in the prior art microprobes. The technology of depositing and etching silicon nitride is very well known.

After the silicon nitride layer 80 has been deposited on the front side of the wafer, a well 83, illustrated in the cross-sectional view of FIG. 6, is photolithographically defined in the backside of the wafer to underlie the intended probe tip. The well 83 corresponds to the aperture 102 to be described later with reference to FIG. 12. The well 83 is etched all the way through the silicon wafer 82, but the as yet laterally undefined silicon nitride layer 80 acts as an etch stop so that a thin silicon nitride membrane remains over the well 83, as viewed from the front side, after the etching.

The processing then returns to the front side. As illustrated in the cross-sectional view of FIG. 6 and the plan view of FIG. 7, the probe layer 80 is patterned and etched in a photolithographic process well known in the fabrication of silicon integrated circuits to leave a probe pattern of a long, narrow probe tip 84 overlying the well 83, a wide support section 86, and a taper section 88 joining the probe tip 84 and the support section 86. The probe tip 84 is aligned to overlie the backside well 83, and the taper section 88 is aligned to overlie sloping sidewalls of the well 83. Exemplary dimensions are a length of 1.5μm for the probe tip 84, a length of 1mm for the taper section 88, a length of 5mm and a width of 200μm for the support section 86. The etching of the probe pattern can be performed by

plasma etching after development of a photoresist mask.

The nitride etching produces the structure, illustrated in the cross-sectional view of FIG. 8. Sloped walls 90, 92, best illustrated in the isometric view of FIG. 10, in the silicon wafer 82 may be formed during the well etching by the known characteristics of some wet etchants such as KOH to leave exposed <111>-oriented planes in silicon, as disclosed by Petersen in "Silicon as a Mechanical Material," *Proceeding of the IEEE*, vol. 70, no. 5, May 1982, pp. 420-457. This leaves a free-standing, generally square probe tip 84 having side dimensions of about 160nm and extending about 1.5μm. The fabrication of a similar structure is disclosed by Boisen et al. and by Kovacs et al. in the previously cited articles.

The width of the probe tip 84 may be determined by the single-step photolithography of the nitride layer 80. Widths of 150nm are achievable with electron-beam lithography. However, e-beam definition of photoresist is an expensive process. Alternatively, a significantly wider probe tip, for example, of 500nm, may be easily defined by conventional lithography. This width can then be reduced by milling the lateral sides of the wide tip with a focused ion beam (FIB). An FIB milling machine produces a very narrow (7nm) beam of, for example, gallium ions which can mill sharp, 5nm edges. Automated FIB machines have been developed for milling of recorder heads, and are commercially available from FEI Company of Hillsboro, Oregon. Similar milling can be used to reduce the thickness of the tip, originally defined by the thickness of the probe layer 80. Selective milling of the thickness or any other dimensional aspect of different probe tips from a single wafer, either prior to or after dicing or sawing, allows tips of different widths, thickness, and/or tip orientations to be fabricated from the same wafer fabricated with a single set of photolithographic masks starting from a uniform thickness of the probe layer 80.

The silicon wafer 82 is then diced or sawed in areas away from the probe tip 84 to form a macroscopic support 94, as illustrated in FIG. 10, which can handled relatively easily. The sloped walls 90, 92 form a skewed pyramidal structure linking the macroscopic support 94 and the microscopic probe tip 84. The rectangular support 94 extends from the base of the pyramid, and the probe tip 84 extends from the apex of the pyramid. The pyramid structure in combination with the tapered portion 88 of the probe layer 80 also allows access to small surface features in the wafer being probed.

The thick support 94 is then fixed to the tab 70 of FIG. 3, similarly to how the prior-

art probe 72 of FIG. 3 is attached, with the square probe tip 84 of the invention projecting downwardly when attached to the profilometer. As shown in FIG. 11, the generally square probe tip 84 having a width of 150nm is smaller than the currently researched trench widths of 180nm. As a result, its tip 84 can fit within the trench 10 all the way to its bottom as long as the bottom trench width is at least 150nm. Furthermore, because the square probe tip 84 has a flat bottom 96 with approximately perpendicular corners 98 and vertical probe sidewalls, it becomes possible for the probe tip 84 to engage and therefore sense the trench side wall 14, thereby providing a more accurate profile of the trench 10. Of course, the fabrication process may round off the bottom corners somewhat, but the horizontal resolution afforded by the generally rod-like probe 84 of FIG. 11 on a sharply sloping sidewall 14 is nonetheless greater than that afforded by the conical probe 20 of FIG. 1. Further, the fabrication process may also round off the side corners of the probe 84 so that it more resembles a cylindrical rod. Nonetheless, such a cylindrically shaped probe still affords the advantages described above. It is to be further appreciated that the two transverse dimension of the probe tip 84 need not be equal providing a square shape. A more rectangular shape is acceptable as long as it can be assured that the small dimension of a narrow trench being probed is aligned with the short dimension of the probe tip 84.

The probe tip produced by the invention is much smaller than any rectangular tip known in the prior art, having a minimum lateral dimension in at least one direction of less than 1μm, preferably less than 250nm. For probing via holes, both lateral dimensions should be less than 250nm. Structural integrity can be maintained by a combination of keeping the length of the probe tip relatively short, for example, less than 5μm, while the pyramidal transition between the probe tip and the silicon support reduces problems of positioning a bulk structure within micrometers of the structure being probed. The relatively short probe length allowed by the pyramidal structure also allows a greatly increased resonant frequency for the probe and produces a stiff probe tip despite its very small cross section.

A significant advantage of micromachined probe tips is that they can be manufactured in large quantities with relatively little additional processing and labor involved for the mulitple probe tips over what is required for one. As illustrated in the plan view of FIG. 12, a large number of probe shapes 100 are etched into the probe layer 80

overlying the silicon wafer 82. The probe shapes 100 are arranged in opposed columns with the probe tips 84 of the two columns facing each other. A single aperture 102 corresponding to the well 83 of FIG. 6 is etched through the backside of the wafer 82. Of course, depending upon the relative sizes of the probes and the wafer, a larger number of probes may be formed in each column. and additional pairs of columns may be formed in parallel with the shapes 100 of the different columns being aligned to allow common dicing. Up to the point in processing illustrated in FIG. 12, it matters little economically how many probe shapes 100 are formed on the wafer. A hundred can be as easily formed as one. Subsequently, the individual probe shapes 100 are separated by dicing in the two dimensions, whether by cleaving or sawing.

Although the embodiment described above uses a silicon nitride probe layer deposited on a silicon wafer, other material combinations are possible. Furthermore, the probe layer may be bonded to a substrate, for example, by atomic bonding or fusion bonding. It is possible to bond a relatively thick free-standing probe layer to the substrate and then to thin the probe layer by, for example, chemical mechanical polishing (CMP). Alternatively, the probe layer may be thermally grown, for example, by oxidation or nitridation of silicon.

The fabrication methods of the invention allows a tiny probe tip to be defined with one horizontal dimension defined by the thickness of a deposited or otherwise bonded planar layer and another horizontal dimension defined by lithography and perhaps by further ion milling. Furthermore, the fabrication techniques are amenable to economies attained in simultaneous processing of multiple tips.

Additional labor can be saved if the probe is integrated with the tab through means of a rotatable probe tip. As illustrated in the side elevational and plan views respectively of FIGS. 13 and 14, micromachining techniques are used to form a cantilevered hinge 110, as disclosed by Wu in "Micromachining for Optical and Optoelectronic Systems," *Proceedings of the IEEE*, vol. 85, no. 11, November 1997, pp. 1833-1855. A hinge shank 112 is formed of a separate layer deposited on a substrate 114. The hinge shank 112 at some point is separated from the substrate 114. The hinge 110 is formed between the hinge shank 112 and the substrate 114 including hinge pins 116 supported by two hinge posts 118. Over the probe shank 112 is formed a probe tip 120 of similar structure and fabrication to that

previously described.

As before, a large number of such probe assemblies may be fabricated in common on a single substrate. After the probe assemblies have been diced from each other, the hinge 110, as illustrated in the side elevational and plan views respectively of FIGS. 15 and 16, is swung downwardly so that its probe tip 120 extends perpendicularly away from the plane of the substrate 114. Finally, as shown in the side elevational view of FIG. 17, a glob 120 of epoxy or other adhesive is applied to the area of the hinge joint to immobilize the hinge 110 and attached probe tip 120 pointing in the perpendicular direction.

The substrate 114 replaces the tab 70 and is directly attached to the beam 60 of FIGS. 3 and 4. Thereby, the tedious labor and failure-prone process of attaching the probe tip to the tab is replaced by the relatively simple and non-precise application of the epoxy.

Although the inventive probe has been described with reference to a rocking-beam atomic force microscope operating in the pixel sampling mode, it can be used in a jumping-mode AFM with other probes and profilometers requiring a very small probe tip.

The invention thus provides a very small probe tip but one that is relatively inexpensive to fabricate at high yields.

What is claimed is:

1. A probe tip formed from a layer formed over a substrate and including a probe end of said layer having a thickness of less than 250nm and a width substantially less than a thickness of said substrate, said probe end being cantilevered from an edge of substrate.

2. The probe tip of Claim 1, wherein said layer is shaped into a rectangularly shaped probe portion, a support portion overlying a full thickness of said substrate, and a tapered portion between said rectangularly shape portion and said support portion.

3. The probe tip of Claim 1, further comprising a pyramidally shaped transition formed in said substrate having said probe end attached to a tip thereof.

4. The probe tip of Claim 1, wherein said substrate is formed from a silicon wafer.

5. The probe tip of Claim 2, wherein said layer comprises silicon nitride.

6. The probe tip of Claim 2, wherein said layer comprises a material selected from the group consisting of silicon, polysilicon, silicon oxide, titanium nitride, silicon carbide, sapphire, and diamond.

7. A probe tip, comprising:
a substrate including integral hinge posts; and
a probe comprising
a probe tip,
a shank integrally joined to said probe tip, and
hinge pins integrally formed in said shank and rotatably captured by said hinge posts, whereby said probe tip and shank are rotatable about a plane of said substrate.

8. The probe tip of Claim 7, wherein said probe tip has a minimum lateral

dimension of less than 250nm.

9. The probe tip of Claim 7, wherein said probe tip comprises a material selected from the group consisting of silicon, polysilicon, silicon oxide, silicon nitride, titanium nitride, silicon carbide, sapphire, and diamond.

10. An atomic force microscope for measuring a distance in a first direction of a feature in a sample, said first direction being perpendicular to a surface of the sample, comprising:

an actuator providing motion in said first direction; and

a probe fixed to said actuator for movement along said first direction adjacent to said surface of the sample and comprising

a substrate fixed to said actuator, and

a probe tip extending along said first direction, formed in a planar layer formed on a surface of said substrate, and having a substantially constant cross section along said first direction near a distal end thereof.

11. The microscope of Claim 10, wherein said substrate comprises crystalline silicon.

12. The microscope of Claim 11, wherein said layer comprises a material selected from the group consisting of silicon, polysilicon, silicon oxide, silicon nitride, titanium nitride, silicon carbide, sapphire, and diamond.

13. The microscope of Claim 10, wherein said cross section has a maximum dimension of no more than 250nm.

14. A method of forming a probe tip, comprising the steps of:

depositing a layer of a material over a substrate;

etching said layer to a layer shape comprising a probe tip portion having a first width and a first length, a support portion having a second width substantially larger than said first

width and a second length substantially larger than said first width, and a taper portion joining said probe tip portion and said support portion; and

removing a portion of said substrate underlying said probe tip.

15. The method of Claim 14, wherein a thickness of said layer and said first widths are both less than 250nm.

16. The method of Claim 14, wherein said removing step forms a pyramidal structure in said substrate having said probe tip portion adjacent an apex thereof.

17. The method of Claim 14, wherein said removing step etches a plurality of said probe structures in said layer and further comprising separating said plurality of probe structures from each other after said removing step.

18. The method of Claim 17, further comprising the step of selectively ion milling said layer to reduce a thickness thereof to a plurality of differing second thicknesses in said plurality of probe structures.

19. The method of Claim 14, further comprising the step of ion milling said layer to reduce a thickness thereof.

20. The method of Claim 14, wherein said etching step includes:

a photolithographic step of defining said probe tip portion to have a third width greater than said first width; and

then ion milling sides of said probe tip portion to reduce said third width to said first width.

21. The method of Claim 14, wherein said etching step etches said layer to a plurality of said layer shapes.

AMENDED CLAIMS

[received by the International Bureau on 22 December 2000 (22.12.00) original claims 1, 3, 10 and 14 amended; remaining claims unchanged (4 pages)]

1. A probe tip formed from a layer formed over principal surface of a substrate, which extends in a first direction, and including a probe end of said layer having a thickness of less than 250nm and a width substantially less than a thickness of said substrate, said probe end being cantilevered in said first direction from an edge of substrate.

2. The probe tip of Claim 1, wherein said layer is shaped into a rectangularly shaped probe portion, a support portion overlying a full thickness of said substrate, and a tapered portion between said rectangularly shape portion and said support portion.

3. The probe tip of Claim 1, further comprising a pyramidally shaped transition formed in said substrate, tapering in said first direction, and having said probe end attached to a tip thereof.

4. The probe tip of Claim 1, wherein said substrate is formed from a silicon wafer.

5. The probe tip of Claim 2, wherein said layer comprises silicon nitride.

6. The probe tip of Claim 2, wherein said layer comprises a material selected from the group consisting of silicon, polysilicon, silicon oxide, titanium nitride, silicon carbide, sapphire, and diamond.

7. A probe tip, comprising:

a substrate including integral hinge posts; and

a probe comprising

a probe tip,

a shank integrally joined to said probe tip, and

hinge pins integrally formed in said shank and rotatably captured by said hinge posts, whereby said probe tip and shank are rotatable about a plane of said substrate.

8. The probe tip of Claim 7, wherein said probe tip has a minimum lateral dimension of less than 250nm.

9. The probe tip of Claim 7, wherein said probe tip comprises a material selected from the group consisting of silicon, polysilicon, silicon oxide, silicon nitride, titanium nitride, silicon carbide, sapphire, and diamond.

10. An atomic force microscope for measuring a distance in a first direction of a feature in a sample, said first direction being perpendicular to a surface of the sample, comprising:

an actuator providing motion in said first direction; and

a probe fixed to said actuator for movement along said first direction adjacent to said surface of the sample and comprising

a substrate fixed to said actuator, and

a probe tip extending along said first direction, formed in a planar layer formed on a principal surface of said substrate, and having a substantially constant cross section along a direction parallel to said principal surface of said substrate near a distal end of said probe tip.

11. The microscope of Claim 10, wherein said substrate comprises crystalline silicon.

12. The microscope of Claim 11, wherein said layer comprises a material selected from the group consisting of silicon, polysilicon, silicon oxide, silicon nitride, titanium nitride, silicon carbide, sapphire, and diamond.

13. The microscope of Claim 10, wherein said cross section has a maximum dimension of no more than 250nm.

14. A method of forming a probe tip, comprising the steps of:

depositing a layer of a material over a substrate having a principal surface extending

in a first direction;

etching said layer to a layer shape comprising a probe tip portion having a first width and a first length, a support portion having a second width substantially larger than said first width and a second length substantially larger than said first width, and a taper portion joining said probe tip portion and said support portion, wherein said first and second lengths extend along said first direction and said first and second widths are perpendicular to said first direction; and

removing a portion of said substrate underlying said probe tip.

15. The method of Claim 14, wherein a thickness of said layer and said first widths are both less than 250nm.

16. The method of Claim 14, wherein said removing step forms a pyramidal structure in said substrate having said probe tip portion adjacent an apex thereof.

17. The method of Claim 14, wherein said removing step etches a plurality of said probe structures in said layer and further comprising separating said plurality of probe structures from each other after said removing step.

18. The method of Claim 17, further comprising the step of selectively ion milling said layer to reduce a thickness thereof to a plurality of differing second thicknesses in said plurality of probe structures.

19. The method of Claim 14, further comprising the step of ion milling said layer to reduce a thickness thereof.

20. The method of Claim 14, wherein said etching step includes:

a photolithographic step of defining said probe tip portion to have a third width greater than said first width; and

then ion milling sides of said probe tip portion to reduce said third width to said first width.

21. The method of Claim 14, wherein said etching step etches said layer to a plurality of said layer shapes.

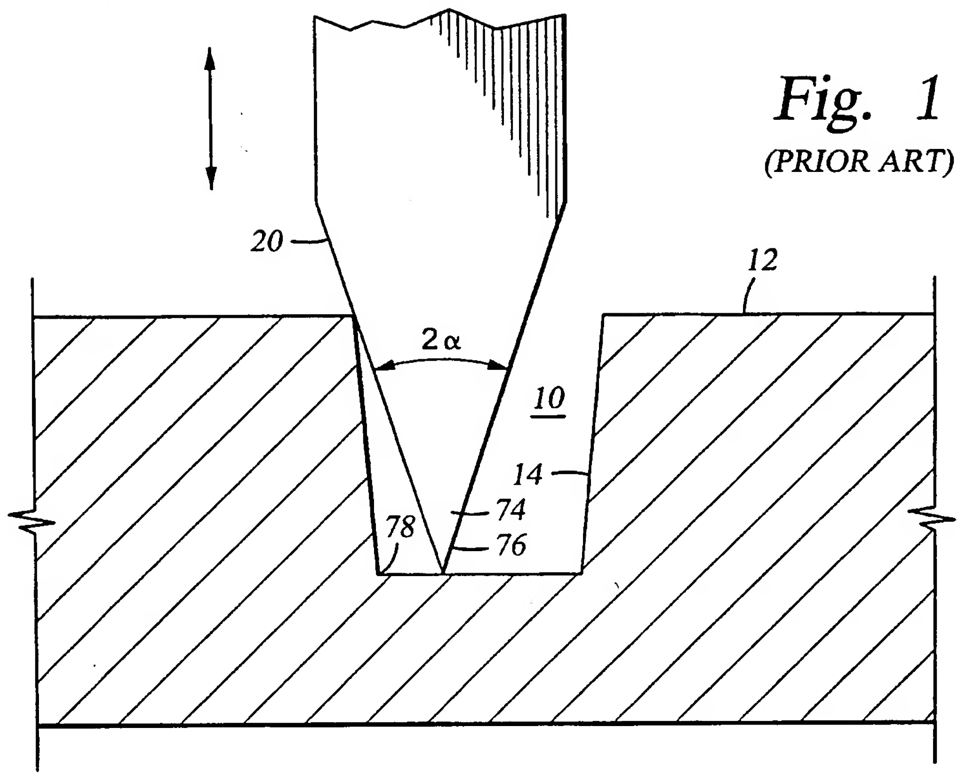


Fig. 1
(PRIOR ART)

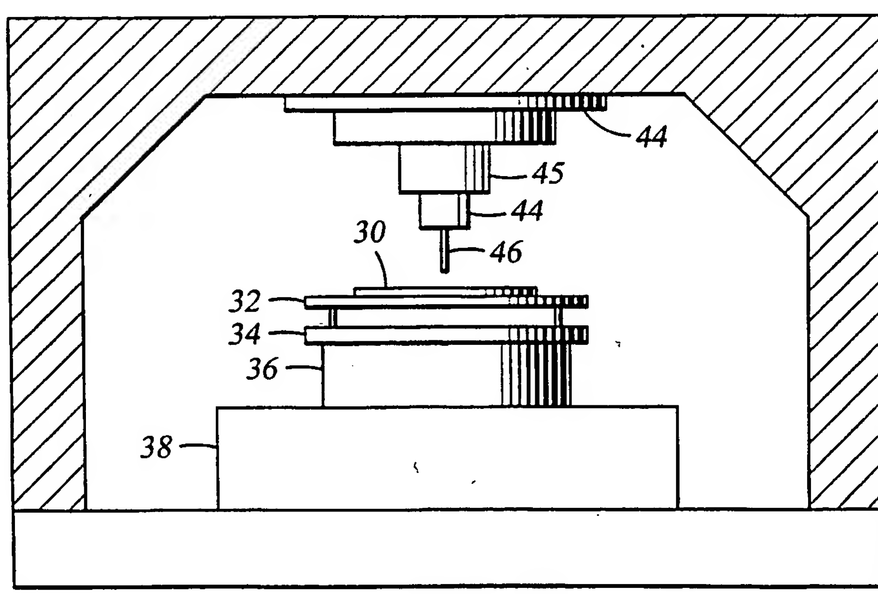


Fig. 2
(PRIOR ART)

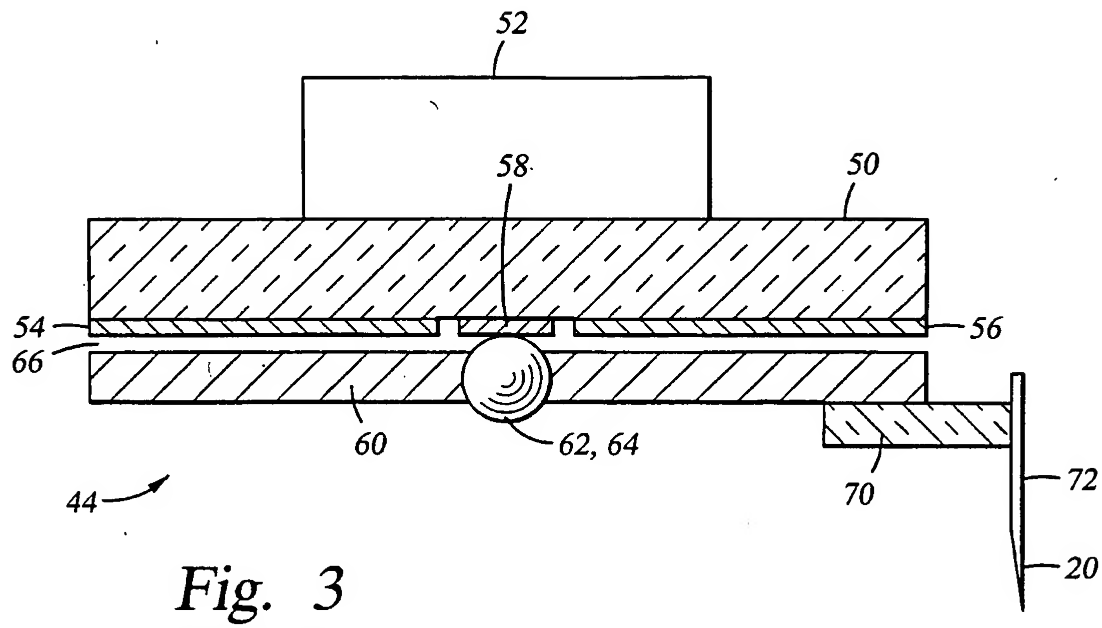


Fig. 3
(PRIOR ART)

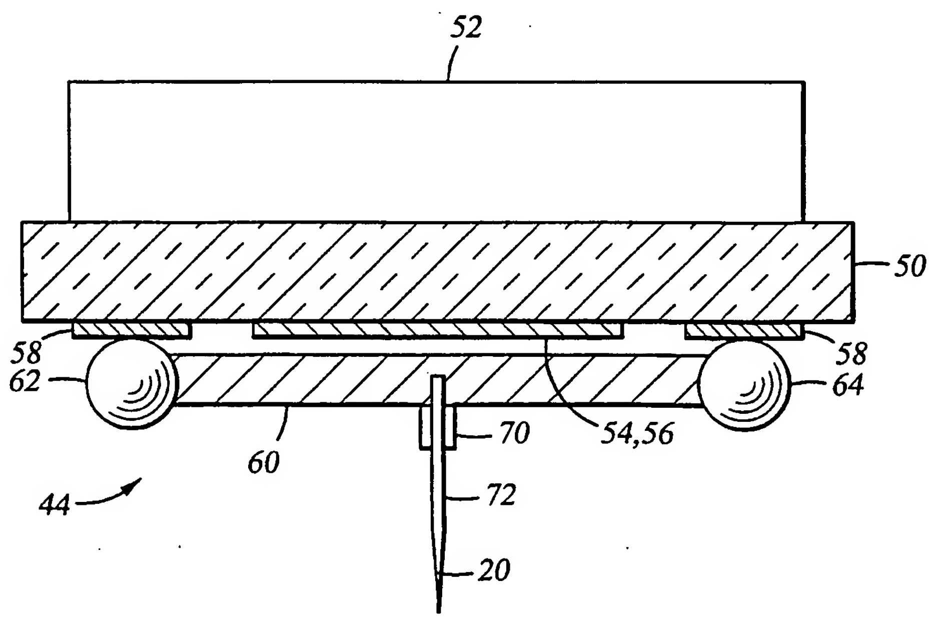


Fig. 4
(PRIOR ART)

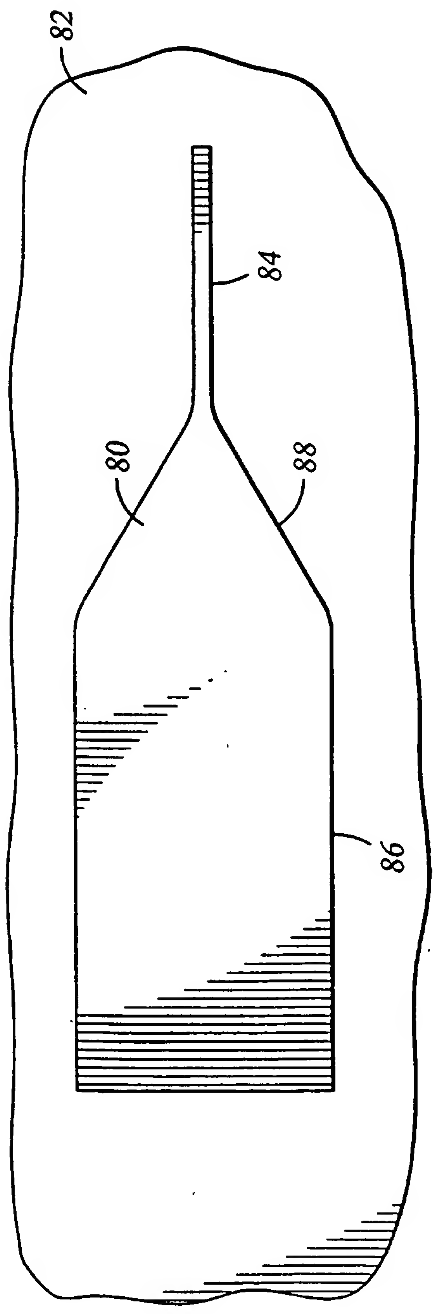


Fig. 7

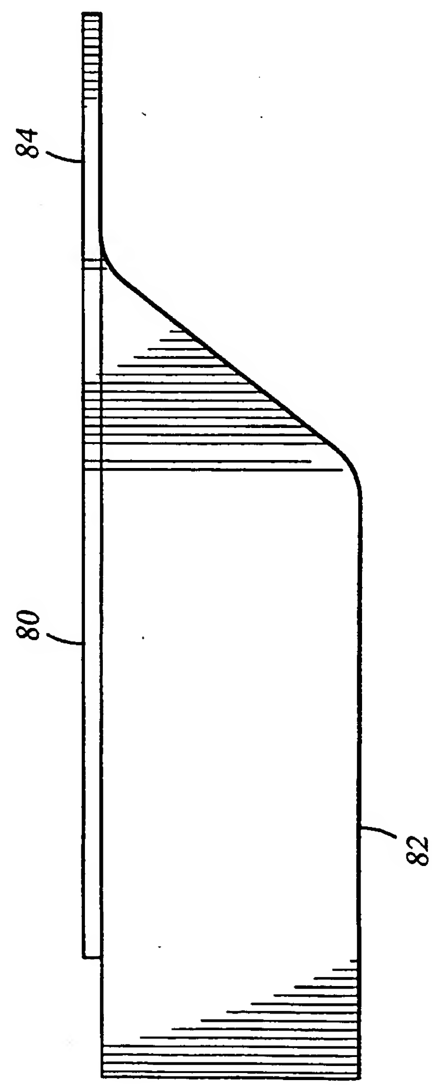


Fig. 8

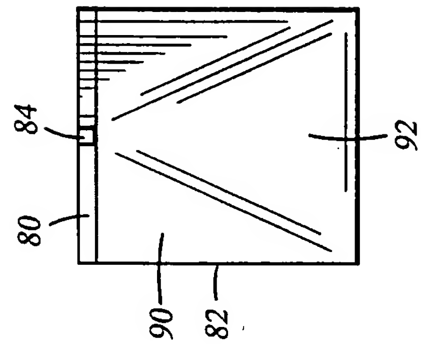


Fig. 9

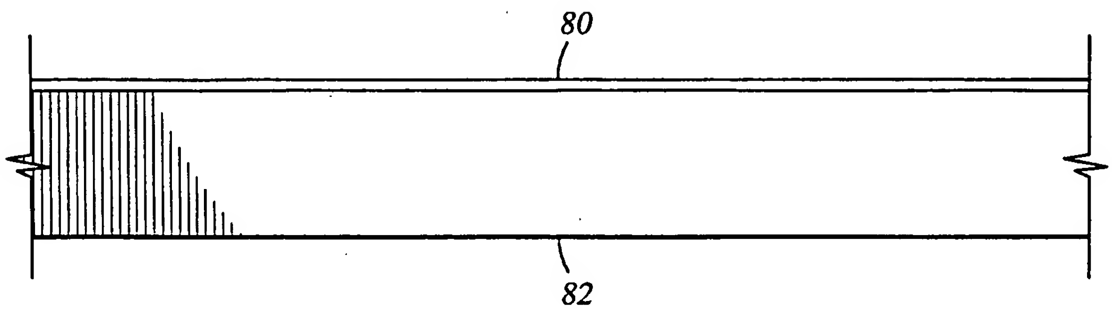


Fig. 5

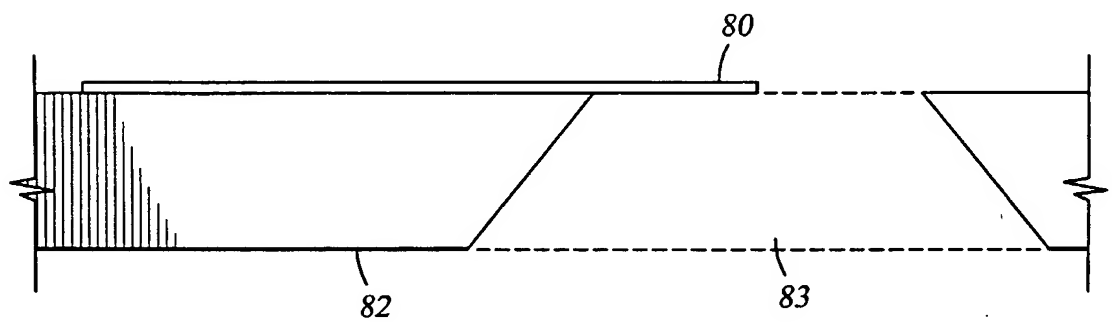
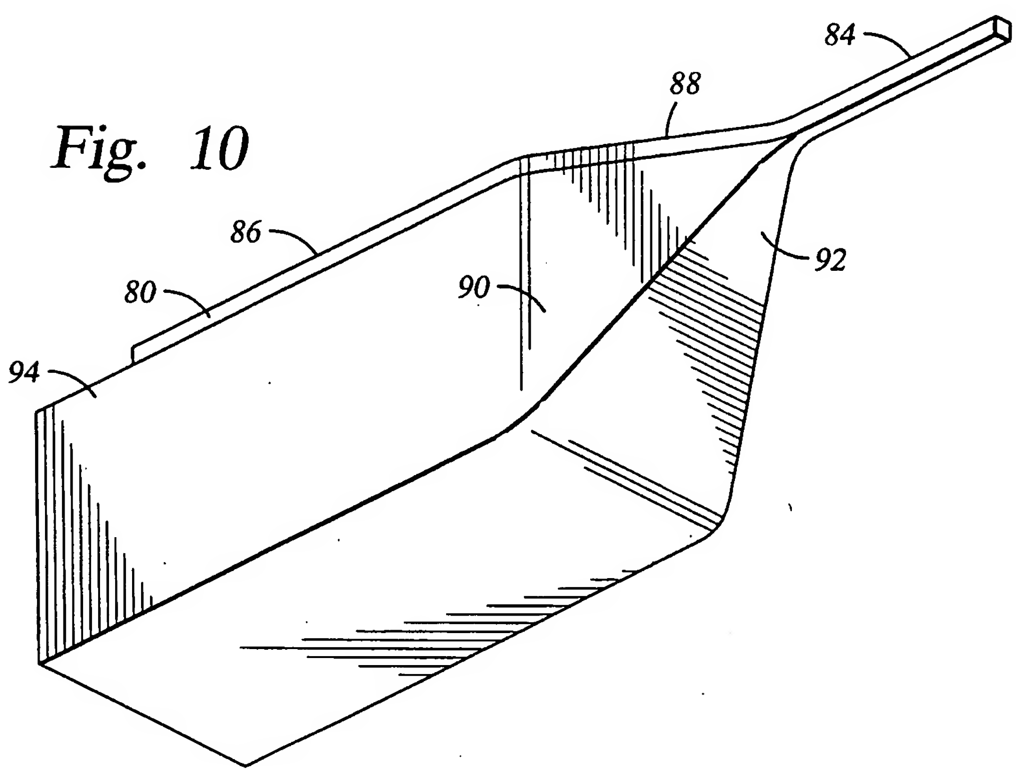


Fig. 6

Fig. 10



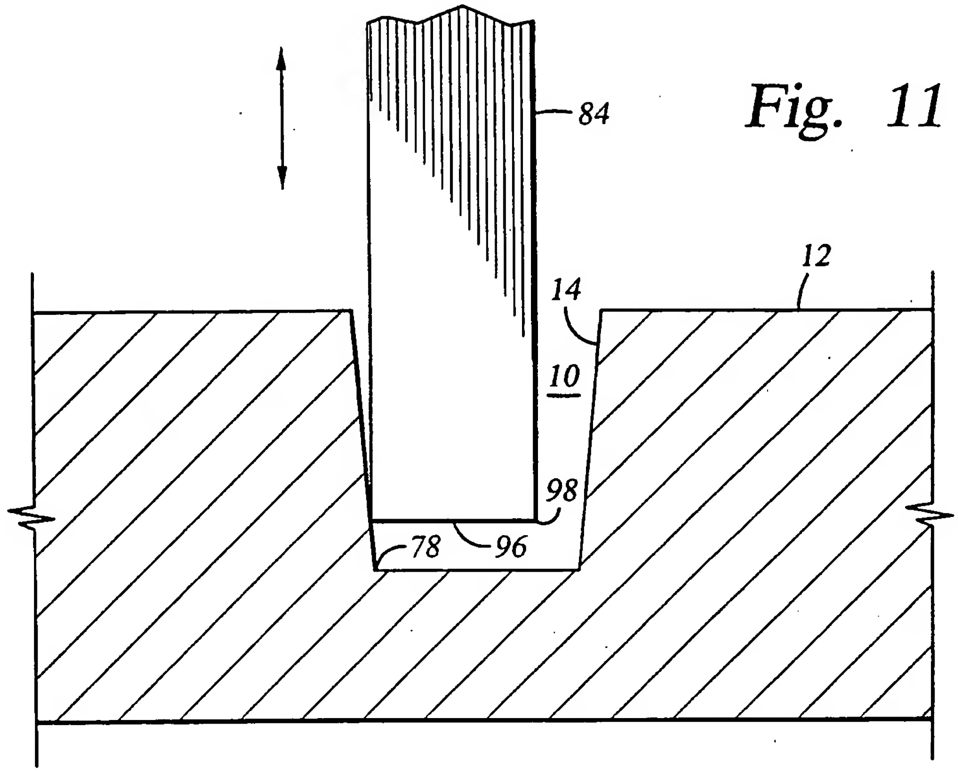


Fig. 11

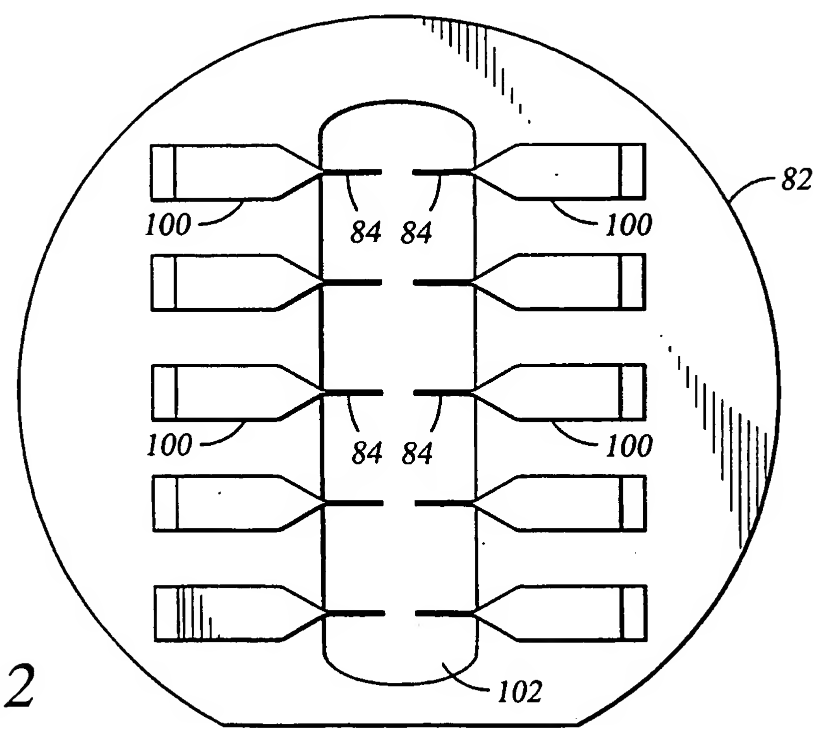


Fig. 12

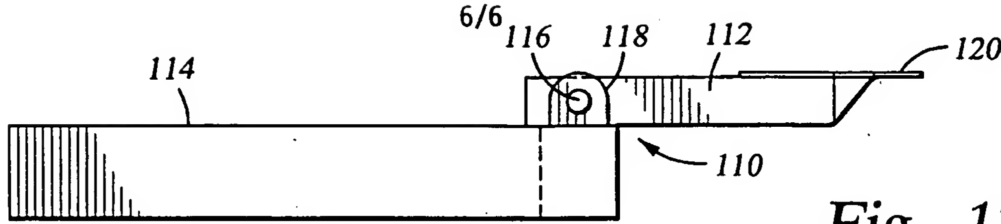


Fig. 13

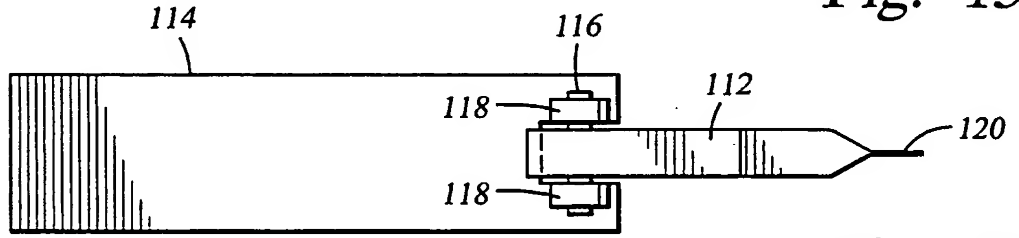


Fig. 14

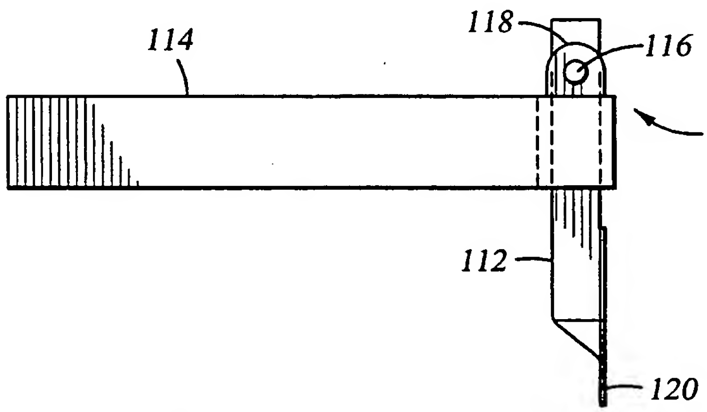


Fig. 15

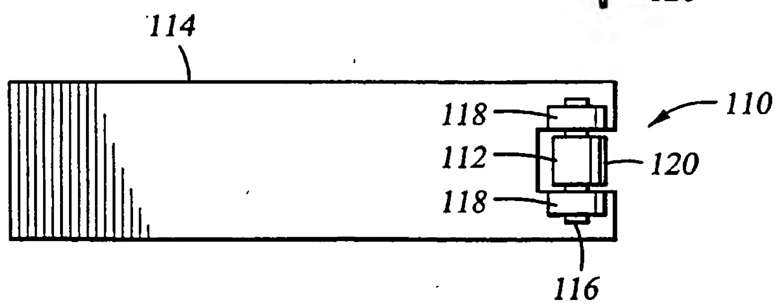


Fig. 16

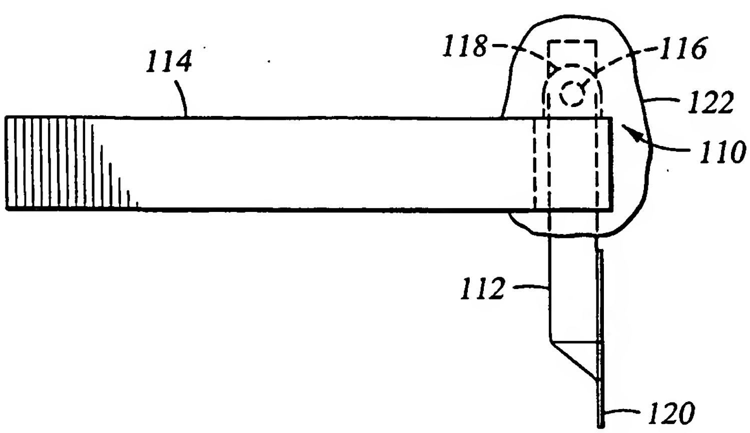


Fig. 17

INTERNATIONAL SEARCH REPORT

Interna al Application No
PCT/US 00/40336

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G12B21/08 G12B21/04 G01B7/34 G01N27/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01B G01N B81B B81C G12B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	ALBRECHT T R ET AL: "MICROFABRICATION OF CANTILEVER STYLI FOR THE ATOMIC FORCE MICROSCOPE" JOURNAL OF VACUUM SCIENCE AND TECHNOLOGY: PART A, vol. 8, no. 4, 1 July 1990 (1990-07-01), pages 3386-3396, XP000148046 cited in the application	1-6, 14-17
Y	abstract; figures 1C,2A	10-13,19
A		9,14-16, 20,21

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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Date of the actual completion of the international search	Date of mailing of the international search report
6 November 2000	15/11/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Clevorn, J

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INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/40336

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
Y	GRIFFITH J E ET AL: "wall angle measurement with a scanning probe microscope employing a one-dimensional force sensor" JOURNAL OF VACUUM SCIENCE AND TECHNOLOGY: PART B, vol. 15, no. 6, 1 November 1997 (1997-11-01), pages 2189-2192, XP000957943 page 2189, right-hand column, paragraph 2 page 2191, right-hand column, line 6 - line 7; figure 3A	10-13
Y	EP 0 413 040 A (IBM) 20 February 1991 (1991-02-20)	19
A	abstract	1,8, 13-21
	column 4, line 50 - line 51; figure 2B	
A	US 5 264 696 A (TODA AKITOSHI) 23 November 1993 (1993-11-23) column 5, line 19 - line 25	17,18,21
A	WU M C: "MICROMACHINING FOR OPTICAL AND OPTOELECTRONIC SYSTEMS" PROCEEDINGS OF THE IEEE,US,IEEE. NEW YORK, vol. 85, no. 11, 1 November 1997 (1997-11-01), pages 1833-1856, XP000755851 ISSN: 0018-9219 cited in the application figure 5	7

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Information on patent family members

International Application No
PCT/US 00/40336

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